Field Characterization of Hydrate-Bearing Core Using X-Ray Computed Tomography

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Outline

- **Motivation**
- **Portable System**
- **Results**
- **Conclusions**

Acknowledgments

- LLNL- Dan Schneberk
- USGS- Laura Stern, Steve Kirby
- Ocean Drilling Program- Frank Rack
- Anadarko Petroleum and Maurer Technology Inc.
- DOE/NETL

Outline

- **Motivation: Methane Hydrate Research**
- **Portable System**
- **Results**
- **Conclusions**

Motivation

- Limited knowledge of hydrate kinetics
- Poor understanding of hydrate/sediment properties

To produce gas from hydrates we need to develop a reliable model for reservoir behavior!

- Can x-ray CT be used to study hydrate kinetics? What is the potential for x-ray CT to spatially and temporally resolve hydrate processes?

Initial Experiment Description

HYDRATE

HYDRATE/ SAND

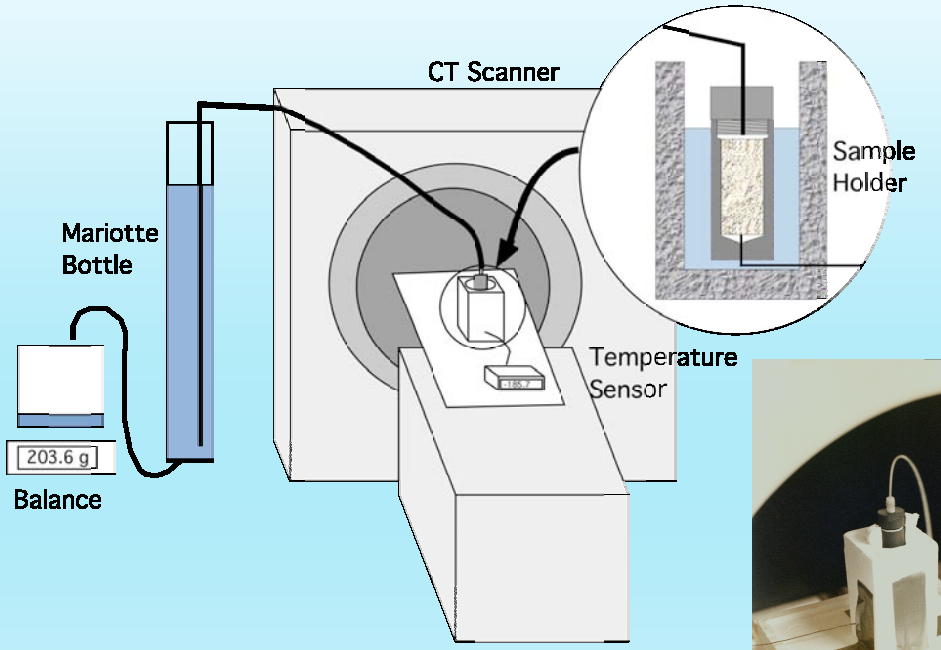
1 inch

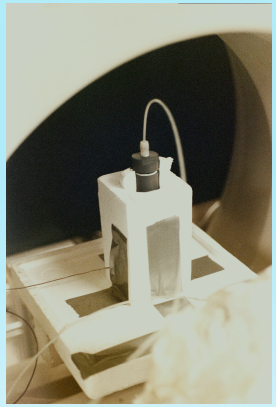
25% sand, 75% hydrate

40% sand, 60% hydrate

60% sand, 40% hydrate

75% sand, 25% hydrate

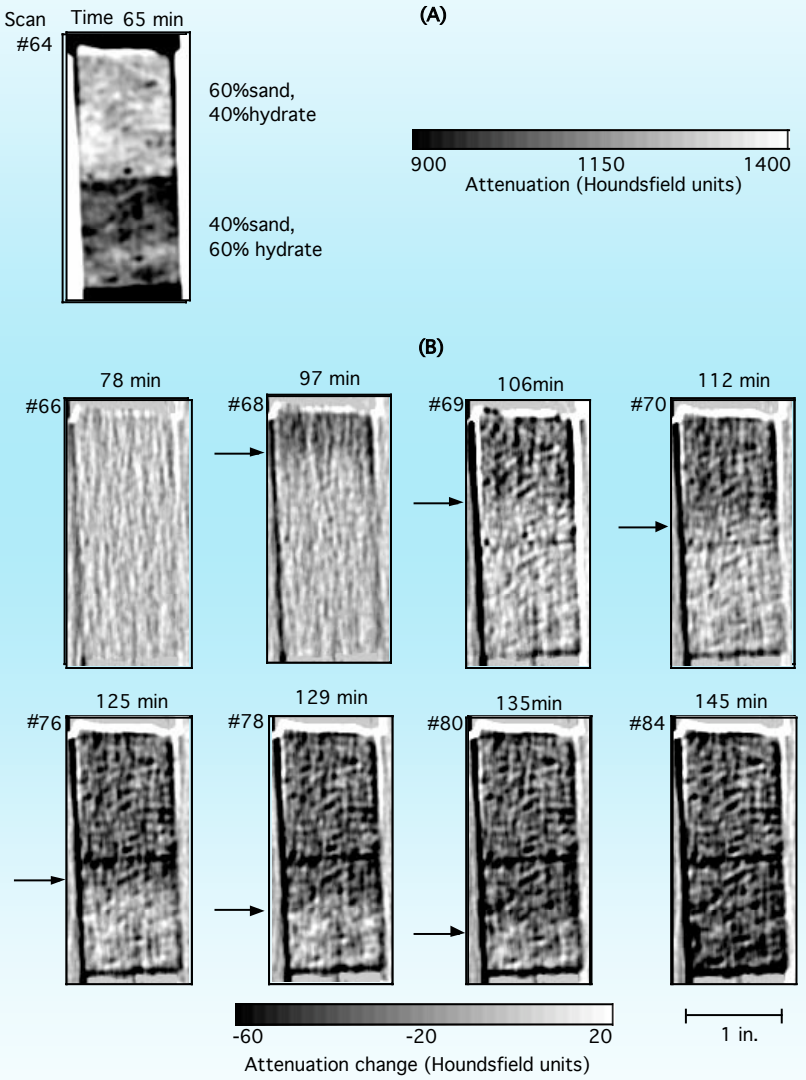


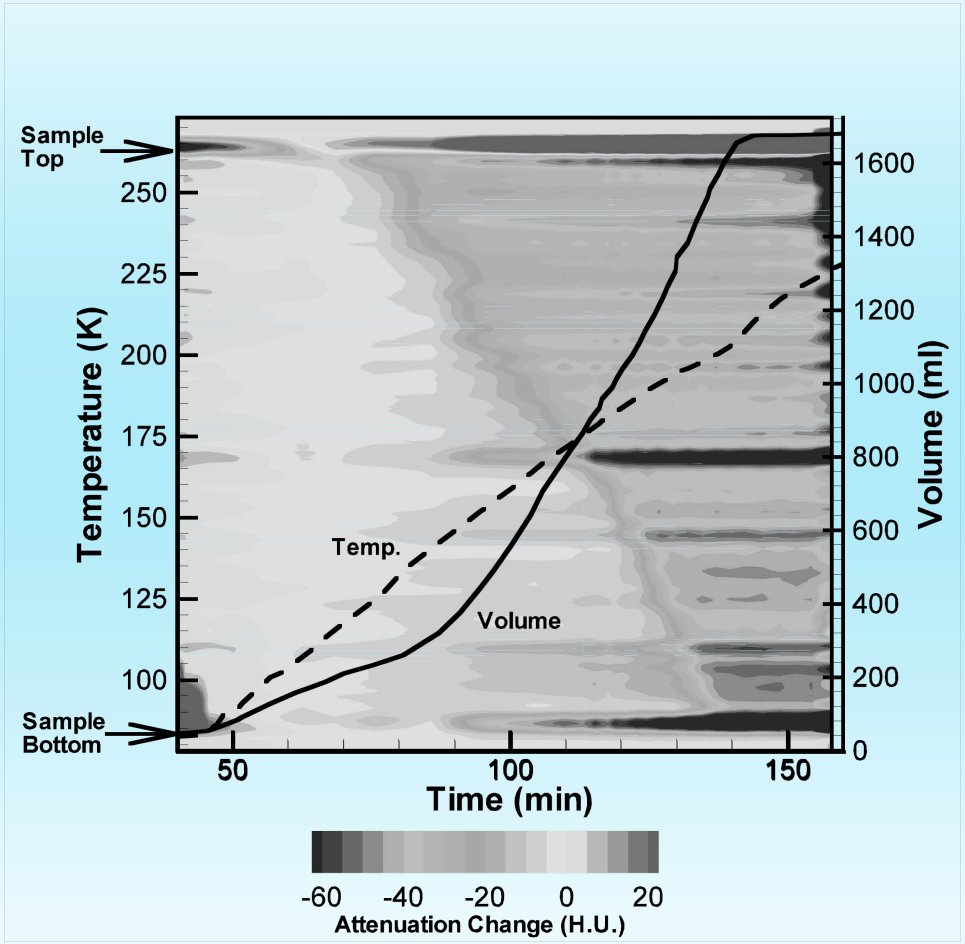


1. Start with sample at LN temperature
2. Allow room heat to progressively warm sample
3. Acquire periodic images while capturing dissociated methane

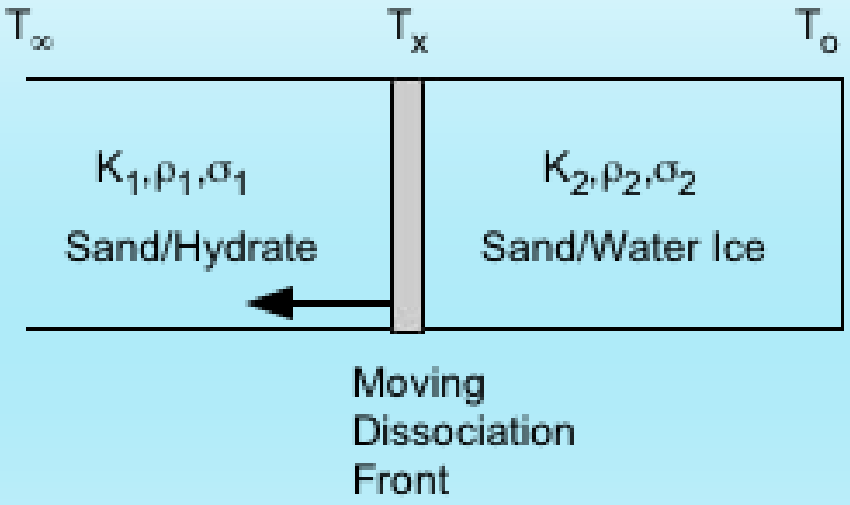
Prior work: Mikami et al. 3rd ICGH

Result: X-ray CT can be used to study hydrate kinetics!

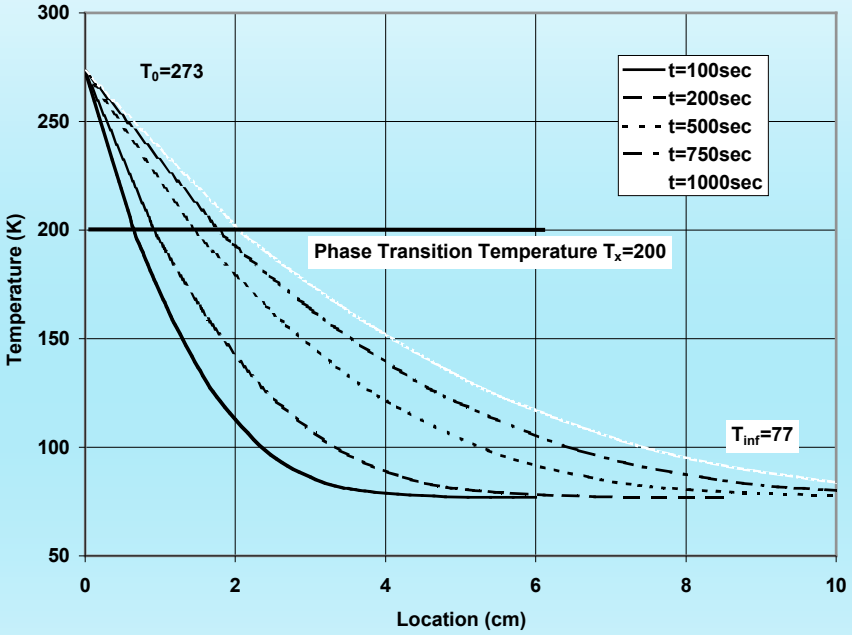




Estimating effective heat transport parameters



Stefan Model of CT Experiment



Stefan moving boundary problem provides numerical model to interpret CT data.

CT provides x(t). Solve for K_1.

Outline

- **Motivation**
- **Portable System: A Cone-Beam System for Imaging Geologic Core**
- **Results**
- **Future Plans**

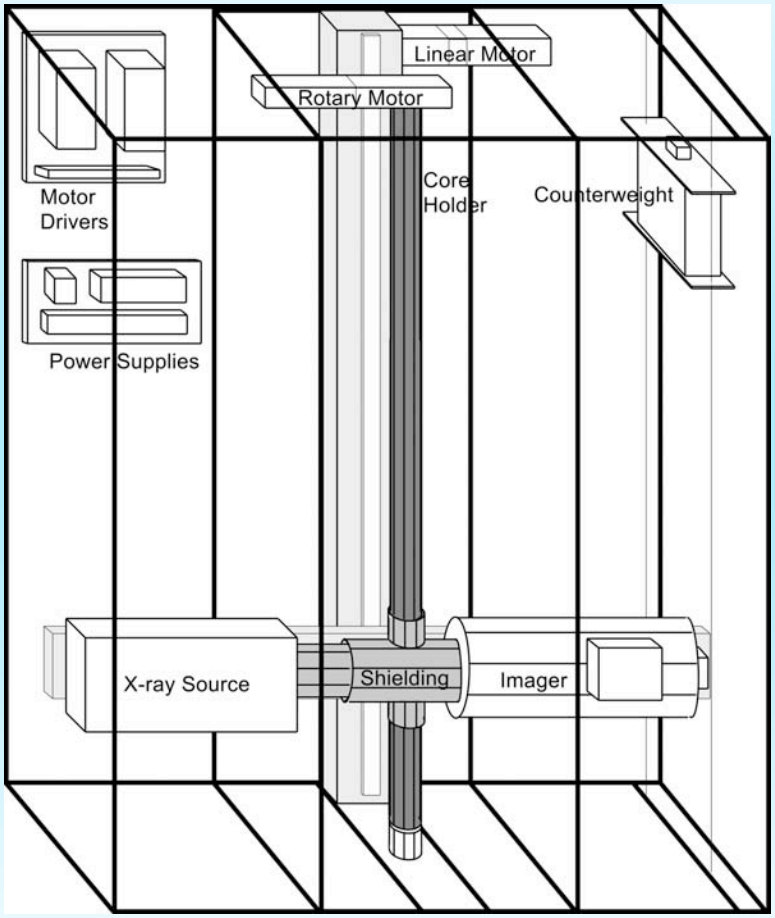
Portable X-ray CT

- Field deployable
- Rapidly characterize cores
- Performance exceeds medical CT systems

ODP Leg 210

Portable System for Geologic Core

- Microfocal X-ray Source
  45–130 kV, 0.5mA
- Cylindrical Sample
  1.5 m _ 9.5 cm
- Core rotated on vertical axis
- 15 cm image intensifier
- X-ray filter for multi-energy scanning
- Attenuation compensator
- Cabinet safe
- Resolution 200µm



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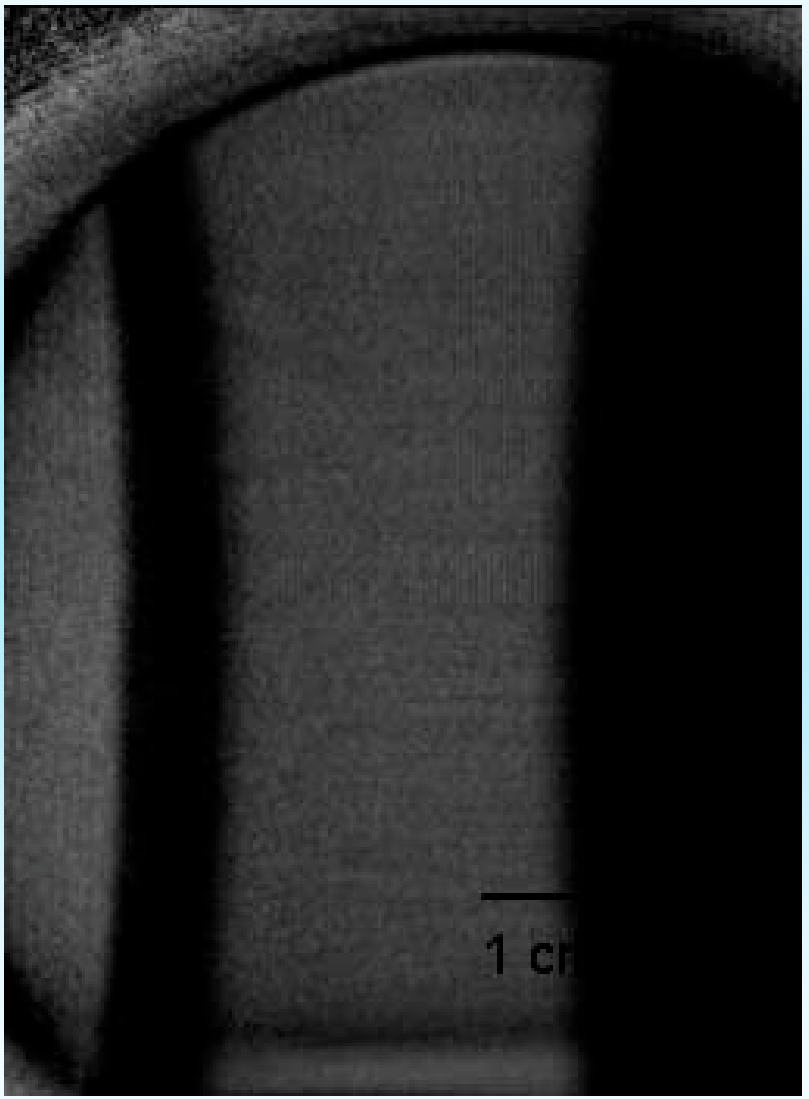

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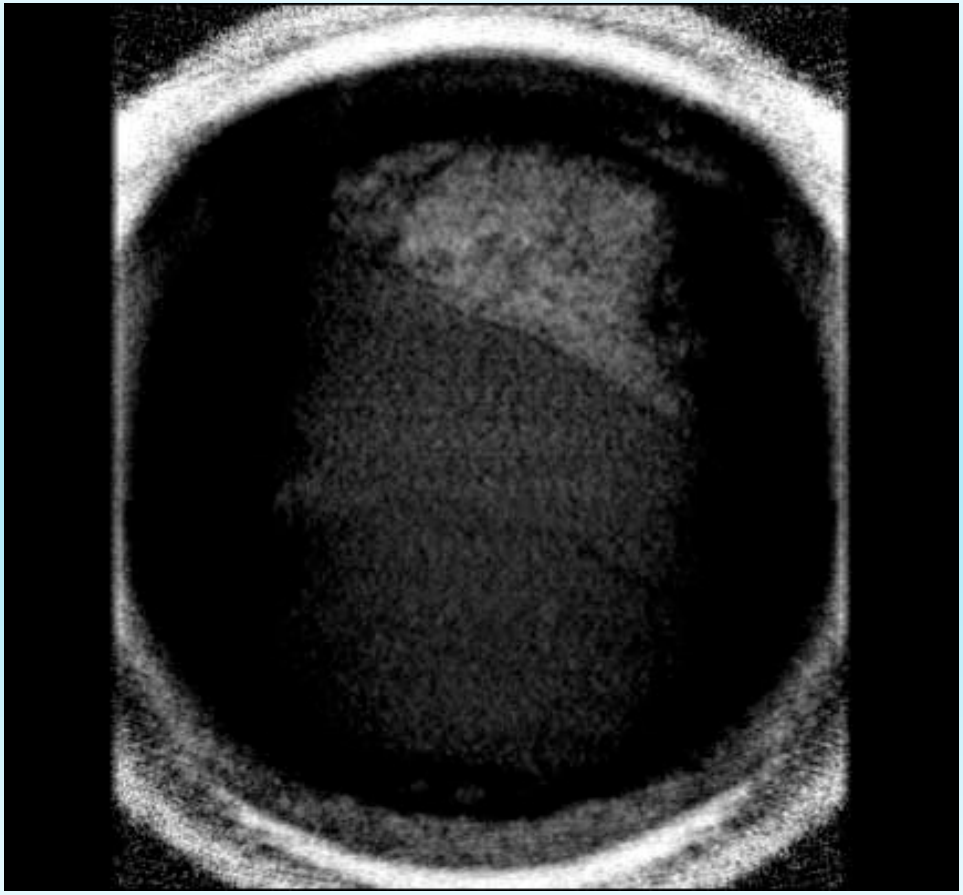
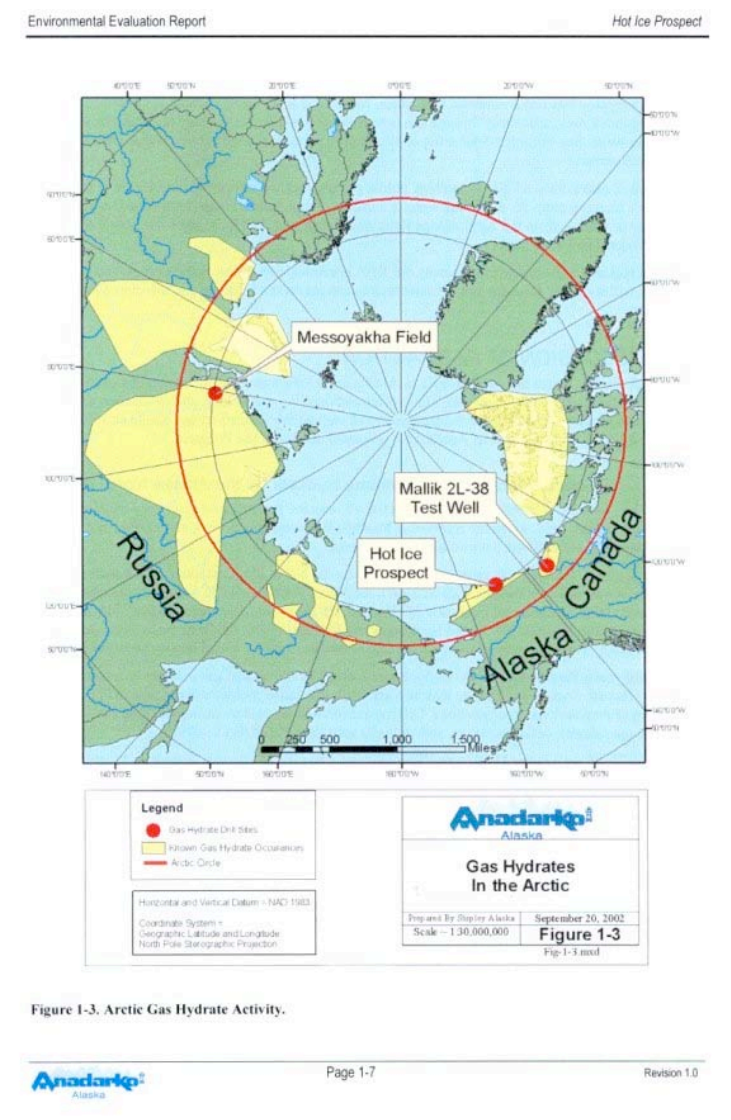
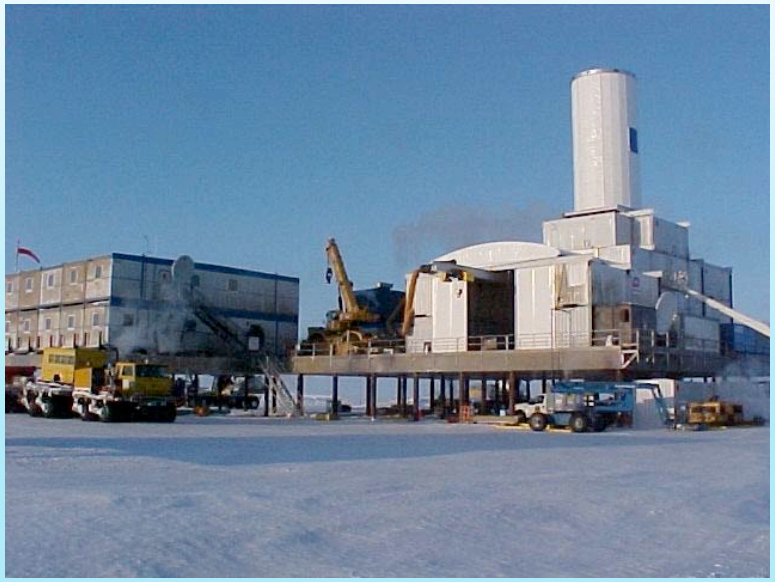


Outline

- Motivation
- Portable System
- Results: Images and analysis of hydrate experiments and geologic core
- Future Plans

Hot Ice #1

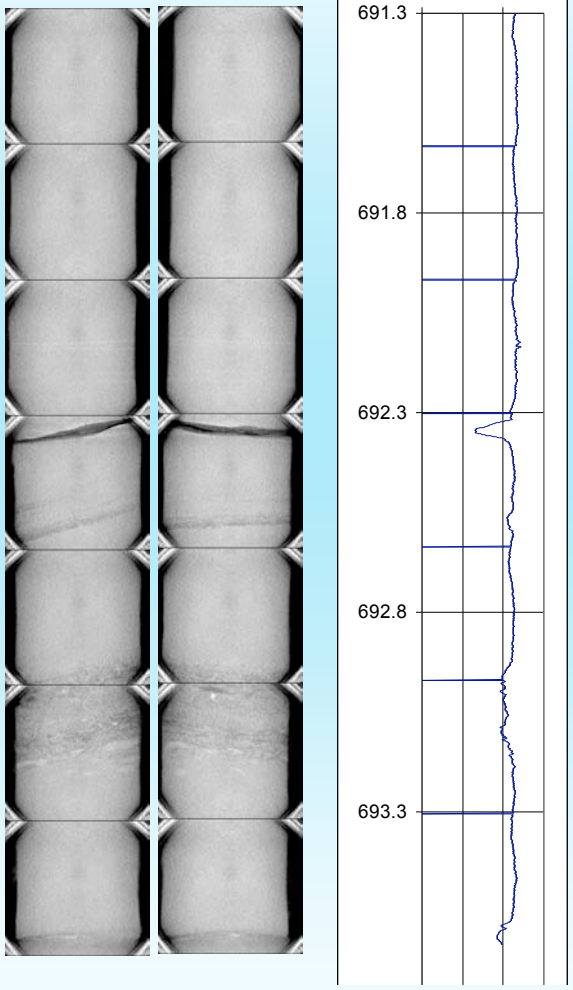




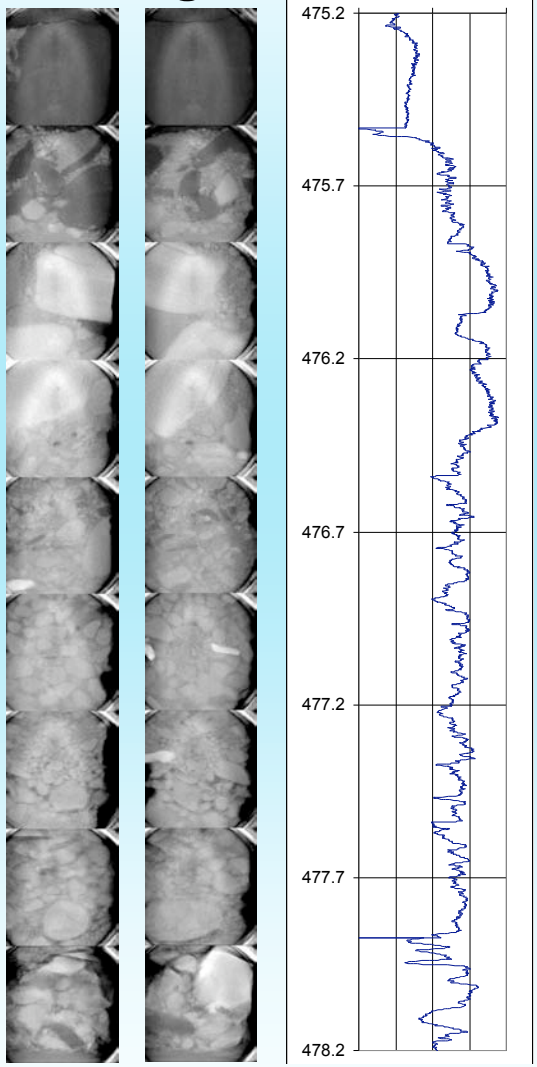
- **Anadarko Petroleum/Maurer Technology/DOE Methane hydrate research well**
- **Drilled down to 1403’ March-April 2003**
- **CT Imaged 159 of 391 Core Tubes (approx 90cm core/tube)**

Core Images from Hot Ice #1

60 Images



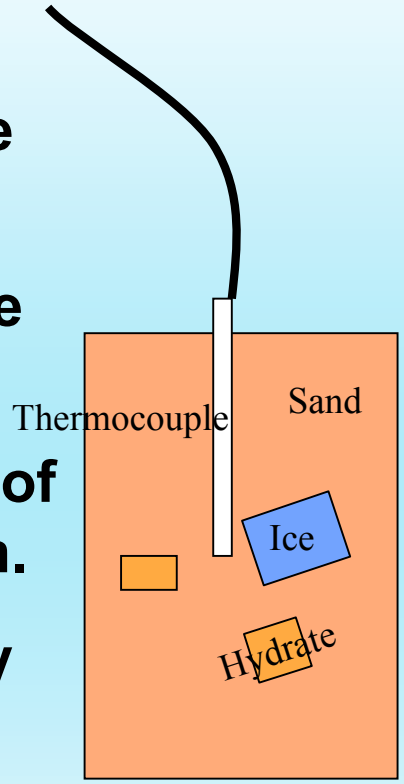
180 Images

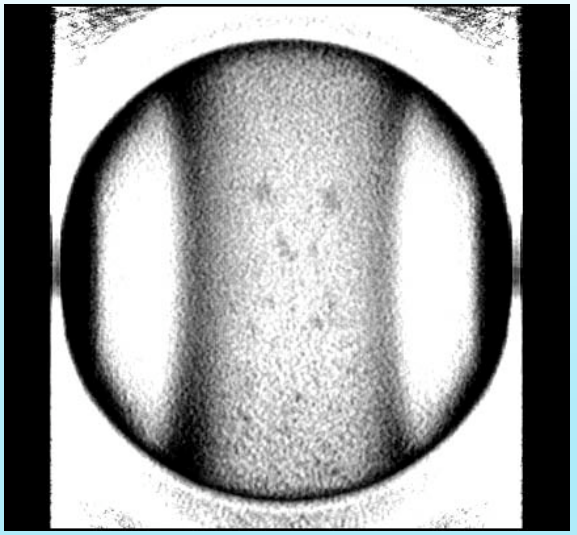


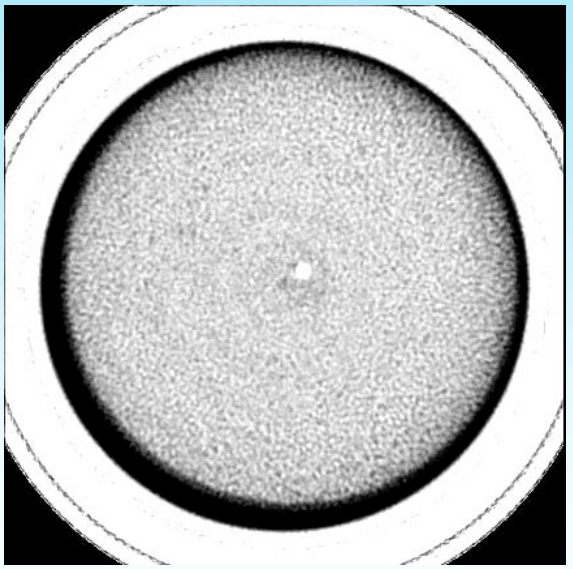
Density logs are assembled from image montages.

Experimental Method

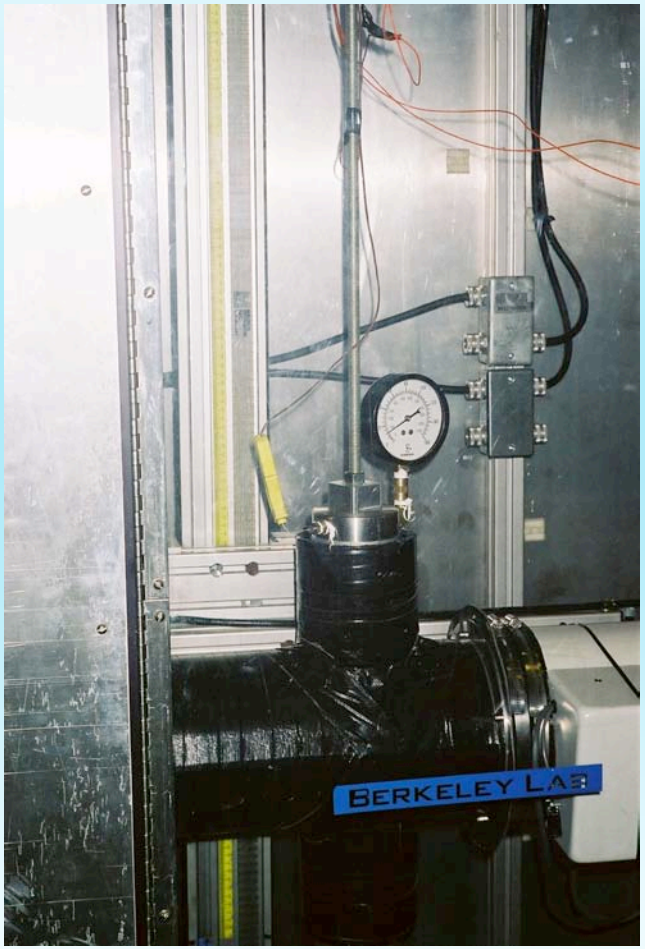
1. Hydrate/Sediment is stabilized in a pressure vessel.
2. Baseline CT images are acquired.
3. Sample is brought out of hydrate stability region.
4. Images are periodically acquired as hydrate dissociates.
5. Differential image analysis performed.

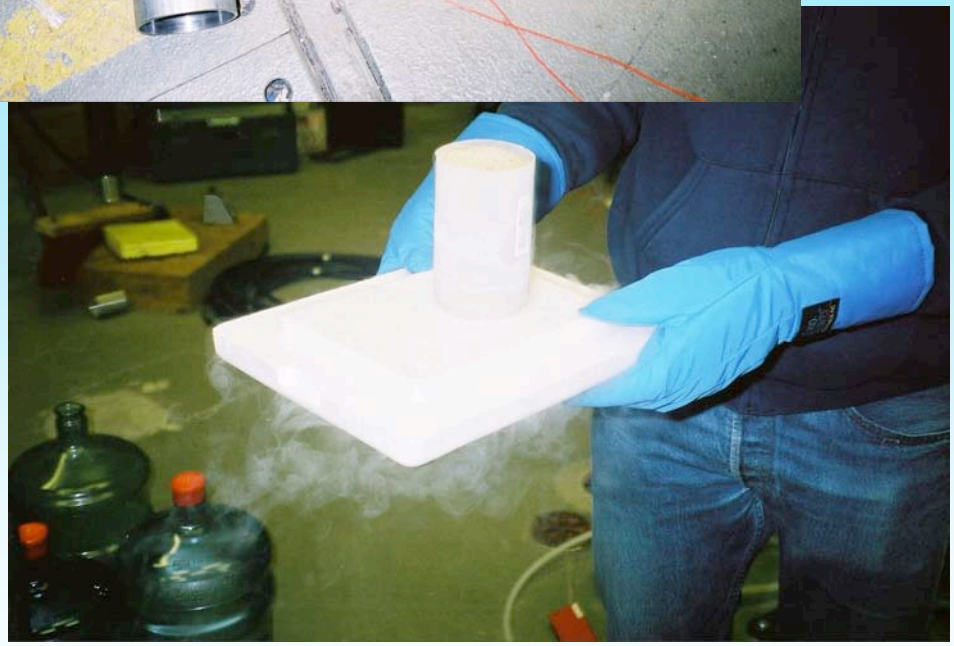




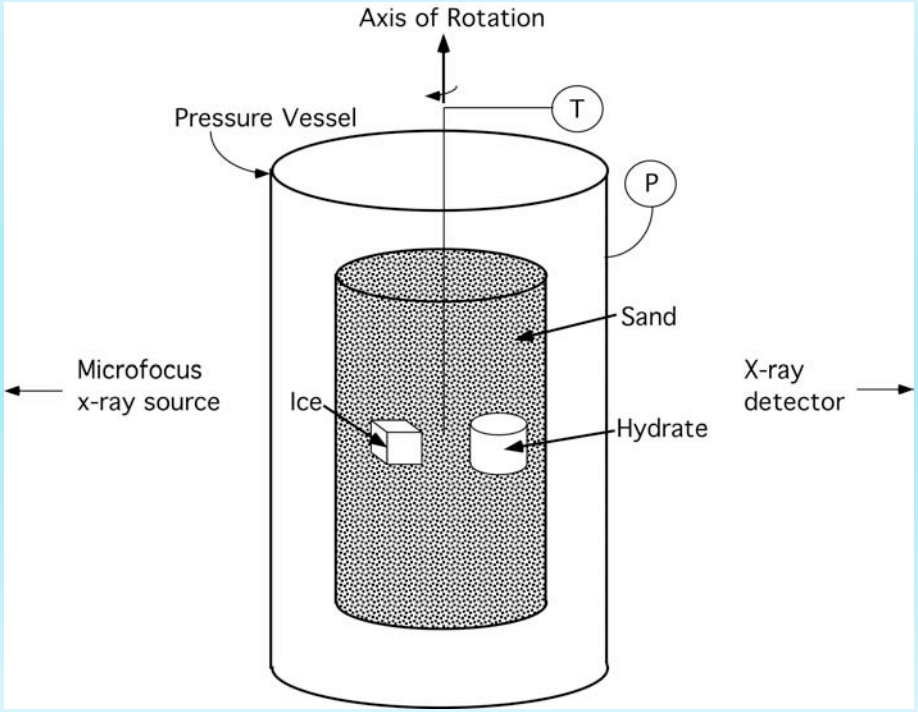


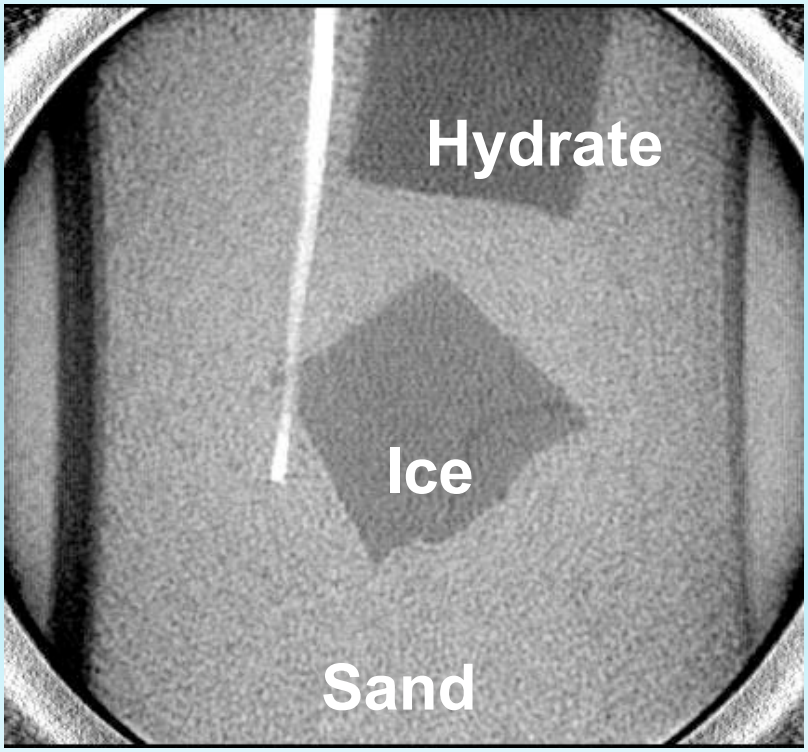
Equipment



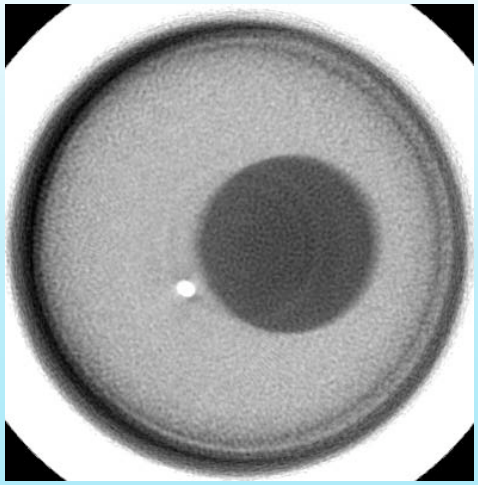


Experiment #1

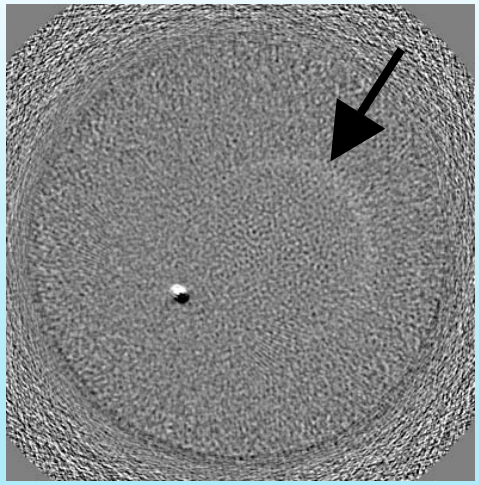




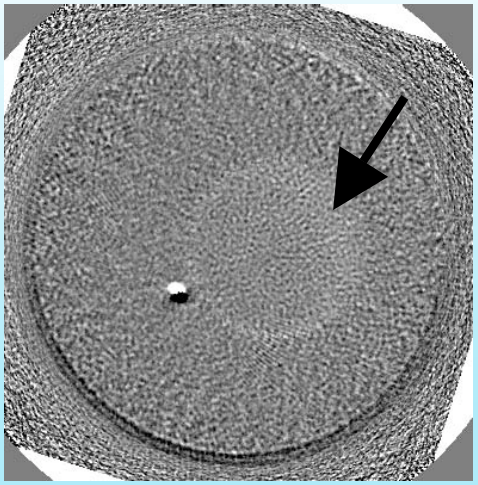
Progression of Hydrate Dissociation



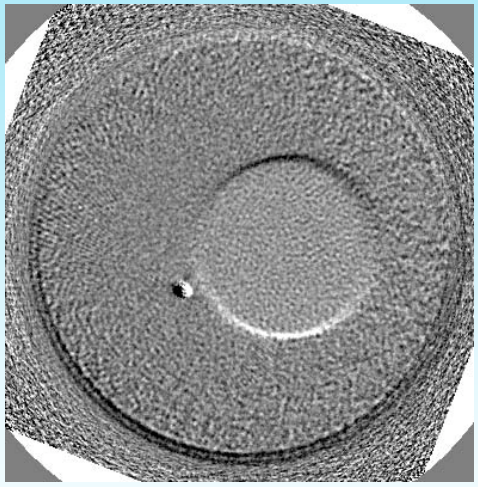
Baseline



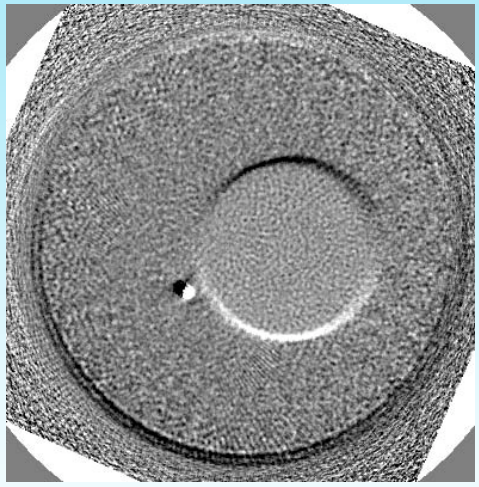
13 min



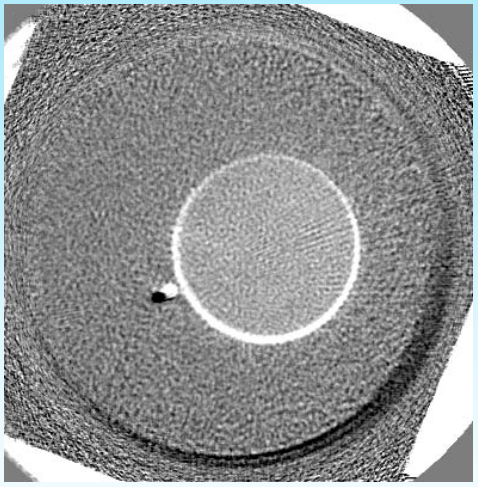
23 min



33 min



41 min

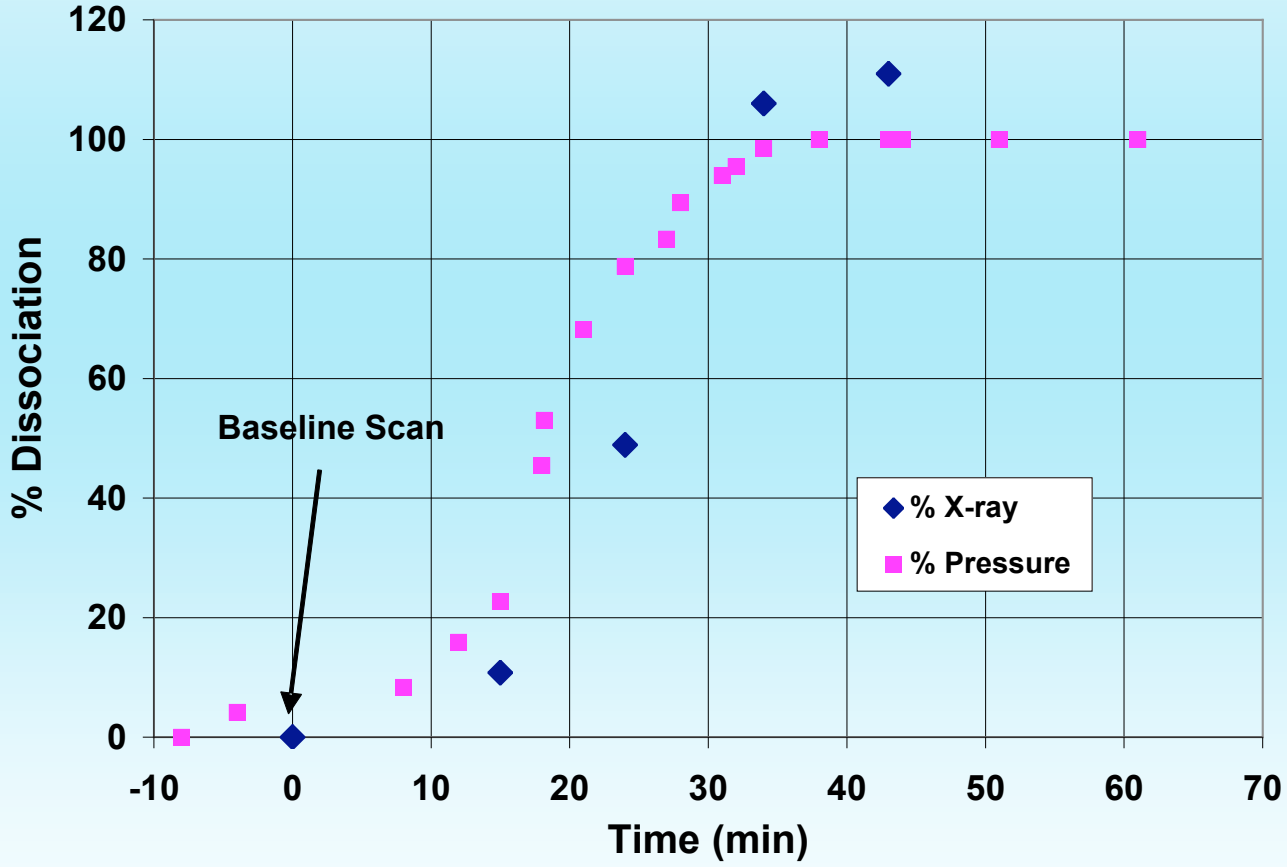


58 min

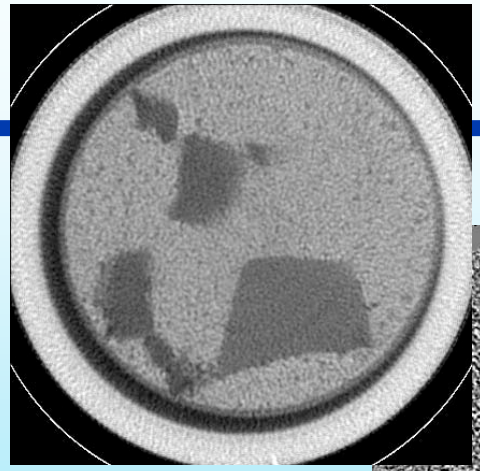
Density Change During Dissociation

Theoretical change in density: -7.7% (Based on initial density)

Estimated from X-ray Images: -8.6%



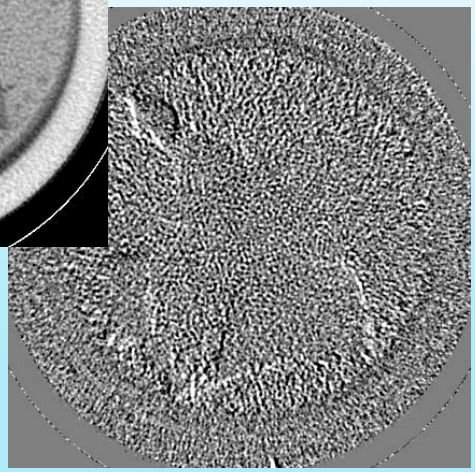
Experiment 2



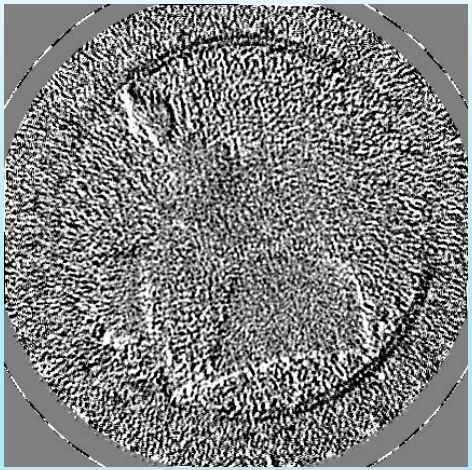
Baseline

Sand + Porous Hydrate + Ice

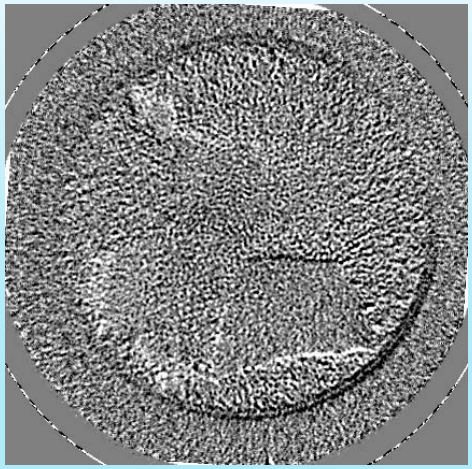
8 min

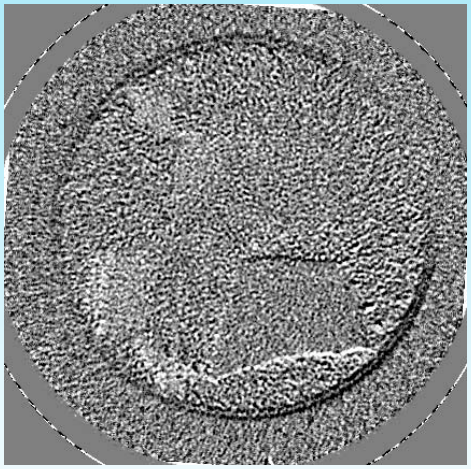


19 min

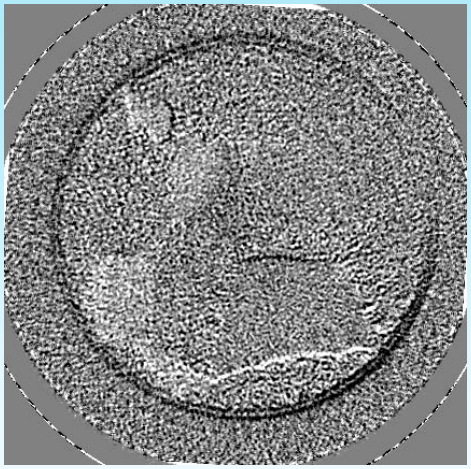


28 min

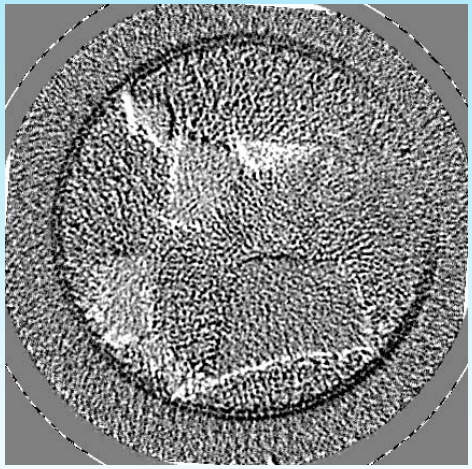




35 min

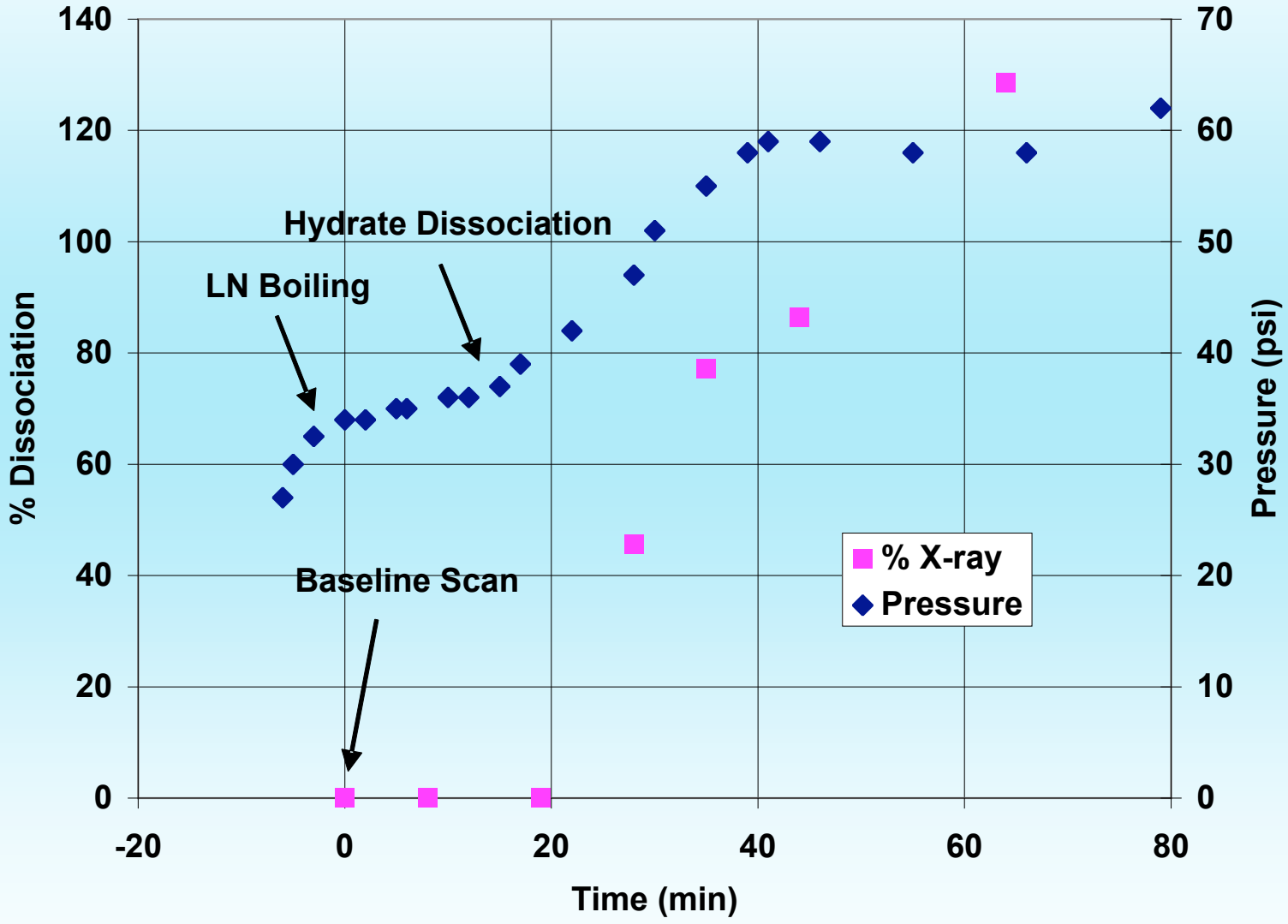


44 min



64 min

Density Changes During Dissociation

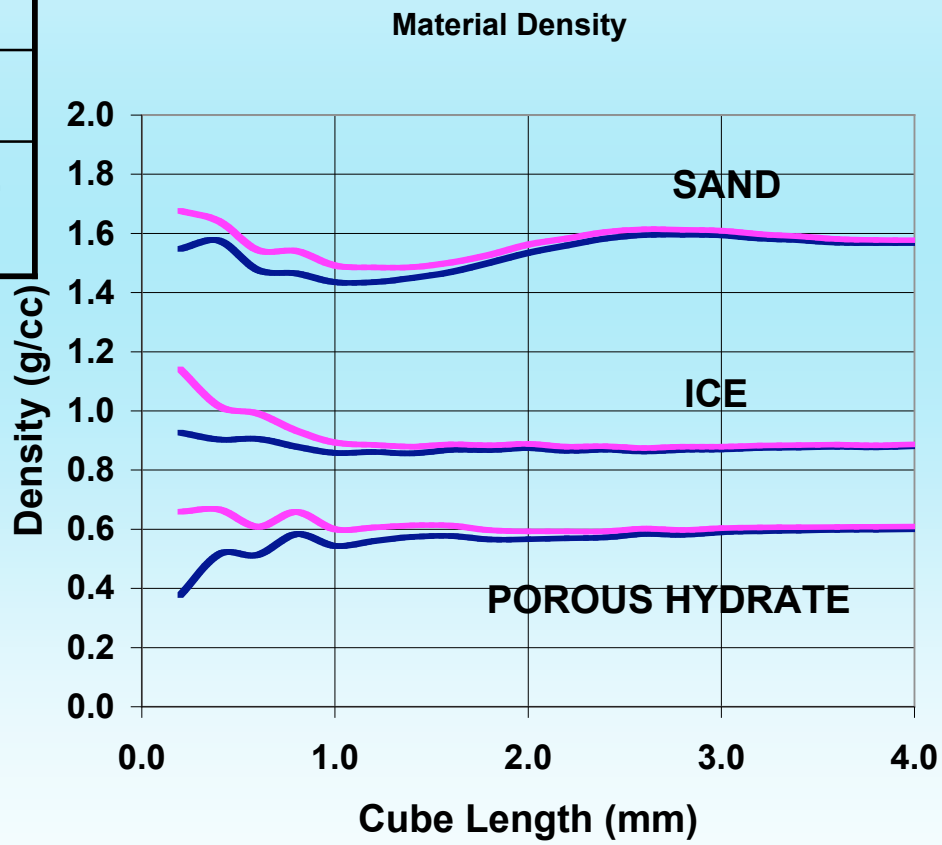


95% Confidence Intervals

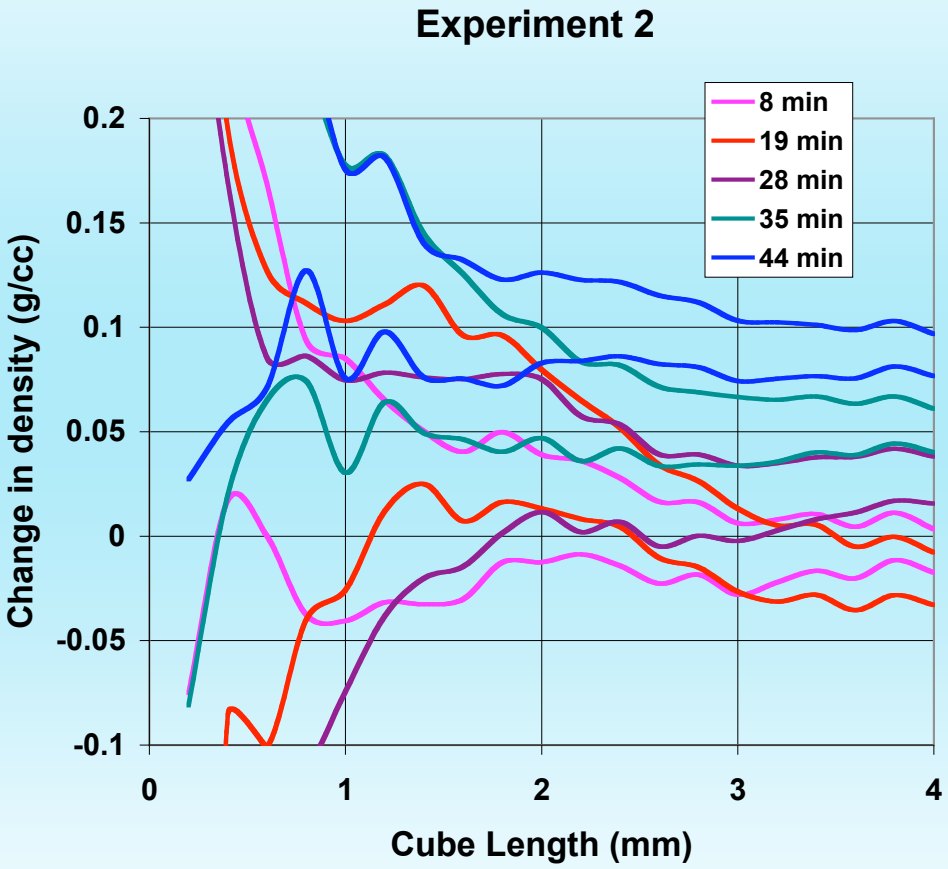
Density Calibration			
	_(g/cc)	MEAN	_
SAND	1.57	1.013	0.041
ICE	.917	.702	0.035
POROUS HYDRATE	.642	.601	0.044

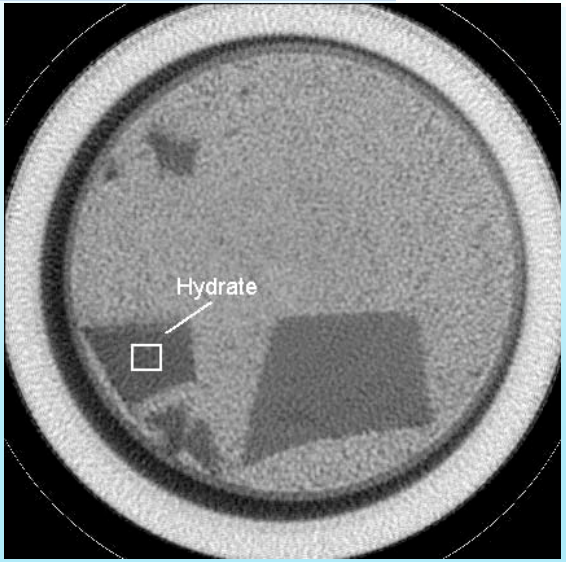
Confidence Intervals:

$$\square(x) = \square(x) \pm t_{0.95,n} \frac{\square}{\sqrt{n}}$$



Cone Beam X-ray CT Accuracy





Cube Size (mm)	95% Confidence Interval _(g/cc)
1	±0.07
2	±0.03
3	±0.02
4	±0.01

Conclusions

- X-ray CT allows rapid characterization of geologic core, revealing sedimentary structures, alterations, fractures, and flow channels and barriers.
- Gas Hydrate dissociation can be both spatially and temporally imaged using x-ray CT.
- A portable x-ray CT can discern density changes of 0.04 g/cc in a 3mm cube. ~30% change in hydrate saturation in a 0.03cc nodule of hydrate.